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June 10, 1965

TRACOR INC.
1701 GUADALUPE ST. AUSTIN, TEXAS 78701 GR6-6601

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TRACOR, INC. 1701 Guadalupe St. Austin, Texas 78701

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TRACOR, INC. 1701 Guadalupe St Austin 1, Texas

AN/SQS-26 ANALYSIS PROGRESS REPORT

Tape Analysis

The effect of target aspect on the performance of a linear correlator is being studied. Sea data tapes recorded under similar conditions except with the target in varying aspect are on hand. This data will be analyzed to yield several points on the signal processing gain curve for each target aspect. These curves will be compared to determine the effect of target aspect on target strength as seen by a linear correlator one hundred cps FM slide of one-half second duration.

The properties of reverberation in surface channel and convergence zone mode are being studied. TRACOR has a set of tapes of CW echo cycles taken with no target present at various depression angles and various relative bearings. This data will be analyzed to study the properties of reverberation in convergence zone and surface channel modes.

Also for a typical echo cycle power spectra will be computed at various times in the cycle. This will be used to obtain a "feel" for the meaning of some of the parameters in reverberation analysis and to possibly improve the reverberation analysis method as a tool.

In the CW processor there is a question as to whether significant improvement in system performance could be realized by using narrower, more nearly matched doppler filters. As the filters are narrowed, approaching the width of the return signal, a gain in signal-to-noise ratio is realized since more of the processing gain is taken coherently. However, theoretical expressions which take into account the statistics and bandwidth of the OR-gate output indicate that a large percentage of this gain is lost when false alarm rates are considered. Preliminary work indicates that, even for ideal 2-cycle return signals, only

small improvement in performance could be realized by altering the present 10-cycle filters. The effects of doppler broadening will likely further reduce any benefits of narrower filters and might even cause a loss in performance when narrower filters are used.

Simulation analysis will be carried out using sea data to determine the significance of the doppler broadened signals to this problem. It is anticipated that this work will be completed early in June.

A technical note is in preparation to describe the results obtained from an analysis of twenty-six sea test tapes recorded aboard the USS Wilkinson (DL-5) during the period (4-9) December, 1964. The tapes were recorded while operating in the Convergence Zone Mode. One-half second FM slide transmissions of 100 c/s bandwidth were used in the tests.

The tests were made in order to investigate Convergence Zone performance versus target aspect and target depth. While the normal Convergence Zone mode transmission is at 0° depression angle, the sonar was often operated in the bottom bounce single ping mode with various depression angles.

Three types of submarine runs were used during the series of tests. These are described as follows:

Type I is a long-range parallel run with the target maintained at perioscope depth and a range of about 74 kiloyards. Measurements were made at beam, 45°, 20°, and bow aspects.

Type IA is the same as Type I except that the target is at 400 feet depth and is at beam and 45° aspects only.

Type II is a long-range closing run on the target with the ships closing within 10 kiloyards of each other. The target is a beam 45°, 20°, and bow aspects.

The results of the analysis will describe the effects of target aspect, depth, and position within the zone upon the effectiveness of the signal processing while operating in the CZ mode.

Reverberation

The computer program for calculating reverberation intensity levels as a function of time after transmission is operational. The intensity computations involve the following parameters.

Transducer depth
Center frequency
Pulse length
Water depth
Average sound velocity
Source directivity function (3-dimensional)
Receiver directivity function (3-dimensional)
Surface, Volume, and Bottom scattering strengths
Surface and Bottom reflection losses

The source and receiver directivity functions used will depend upon the sonar system under consideration. The program is presently set up to compute these functions for the AN/SQS-26 system. To specify a particular transmitting or receiving beam pattern the horizontal and vertical phasing and shading values for that beam at the desired depression angle are included among the input parameters to the program.

Values of bottom and surface reflection losses will be influenced by such factors as wind speed, sea state, and the particular area of the ocean under consideration. Average values for these losses now being used are 12 dB and 3 dB for the bottom and surface, respectively, for 3.5 kc/s. Average scattering strengths for bottom, surface, and volume can be determined

from a comparison of predicted and measured reverberation levels. This will be done when the necessary calibrated sea data becomes available.

The results of an investigation of the reverberation level stability over consecutive echo ranging cycles, briefly discussed in the last progress report, are summarized in a technical memorandum now in press.

Larger Bandwidth Pulses

An analysis of experimental sea test data is being made to determine the relation of the multipath effects to transmission bandwidth. The experimental bandwidths used were 30, 100, 200, and 400 cycles per second. The objectives of the analysis are:

(1) To determine, for each bandwidth, the extent of energy splitting in the experimental sea test data and from this to describe the effective relative performance for each transmission bandwidth.

(2) To develop an analytical model to describe the processing gain of a linear correlator followed by a linear detector-averager using signals of sinusoidal, sine x/x, and Gaussian form for variations of the parameters of signal and reverberation bandwidth, pulse duration, and input signal-to-noise ratio. To demonstrate the validity of this model by a computer simulation using the same bandwidths as in the sea data. The purpose of this work is to support the sea test data analysis and yield a foundation upon which to base analysis to describe the orgins of the energy splitting observed in the sea test data.

The sea test data analysis and the development of the analytical model are complete. The results show that the processing gain from increasing the bandwidth is reduced to one-half the predicted gain due to the effects of energy splitting. A technical note on this work is in preparation.

Performance Analysis of the TRACOR Linear Correlator

An analysis of the sea test tapes is being carried out to determine the performance characteristics of the TRACOR linear correlator. The primary objectives of this study are:

(1) Compare the TRACOR linear correlator, the sonar's clipped correlator, and a simulated linear correlator on the basis of output signal-to-noise ratio.

(2) Determine whether the output of the TRACOR linear correlator is adequately normalized.

In order to obtain an adequate comparison of the correlator outputs the following analyses are in progress:

(a) Determine the output signal-to-noise ratios for the various correlators.

(b) Establish criteria of equal merit taking into account the output statistics.

The question of adequate normalization will be attacked using two basically different approaches. These are both based on the fact that inadequate normalization will show up as time fluctuations in the mean and standard deviation of the output noise.

The first procedure considered is as follows:

(1) Compute the signal-to-noise ratio using the mean and standard deviation calculated from a small section of noise adjacent on both sides of the signal.

(2) Compute the signal-to-noise ratio using the mean and standard deviation calculated from a large section of noise in the region of the signal.

If the background statistics are stationary, these calculations should agree.

The second procedure is as follows:

(1) Select a large section of output noise from the correlator.

(2) Establish a threshold and measure the time separation, Δt, between each two adjacent crossings of the threshold.

(3) Compute the statistical distribution of the Δt's.

If the background statistics are stationary, the results should be an exponential distribution.

To date several sea test tapes have been analyzed for signal-to-noise comparisons. The tape analysis will continue and all analysis should be complete early in June.

Mutual Interference

Analysis of sea test data taken to characterize mutual interference and evaluate its significance is substantially complete. This data analysis consisted of a study of signals taken at various locations in the AN/SQS-26 (XN-2) system when it was being operated in the presence of a second AN/SQS-26 sonar. Results show that performance can be degraded by interference, particularly when operating in the BBT and 1/3 CZ search modes. The extent of the interference is a function of the level of the interfering transmission, the frequency, and the decay time of the reverberation associated with that transmission.

The results indicate that improved pre-AGC frequency discrimination and appropriate coordination of multiple sonar activity may minimize this interference. A report on this work is being prepared.

The computer program, described in the last progress report, for calculating the sound intensity level at one ASW ship due to transmission by another ASW ship is now operational. In order to isolate areas of particular interest computer runs are in progress with several sets of input parameters such as transmitting and receiving beam patterns and their relative orientation, ship separation and water depth. These parameters were chosen as representative of those imposed by various tactical configurations. Preliminary calculations indicate that there are at least five paths for sound transmission which must be considered. The contributions of each of these five paths are being computed and plotted separately so that the relative importance of each may be determined.

Beamforming and Receiver Design Concepts

Preliminary estimates have been completed for the quantity of storage, technically feasible logical clocking speeds, and the quantity of arithmetic equipment required to implement completely digital beam formation in the SQS-26 preformed beam system. These estimates are based on an assumed digital beamforming having the following characteristics.

(1) The beams will be formed simultaneously in both elevation and azimuth.

(2) Provision is included for beam depression from 0° to 42° in increments of approximately 5°. This inherently includes the necessary provisions for vertical stabilization.

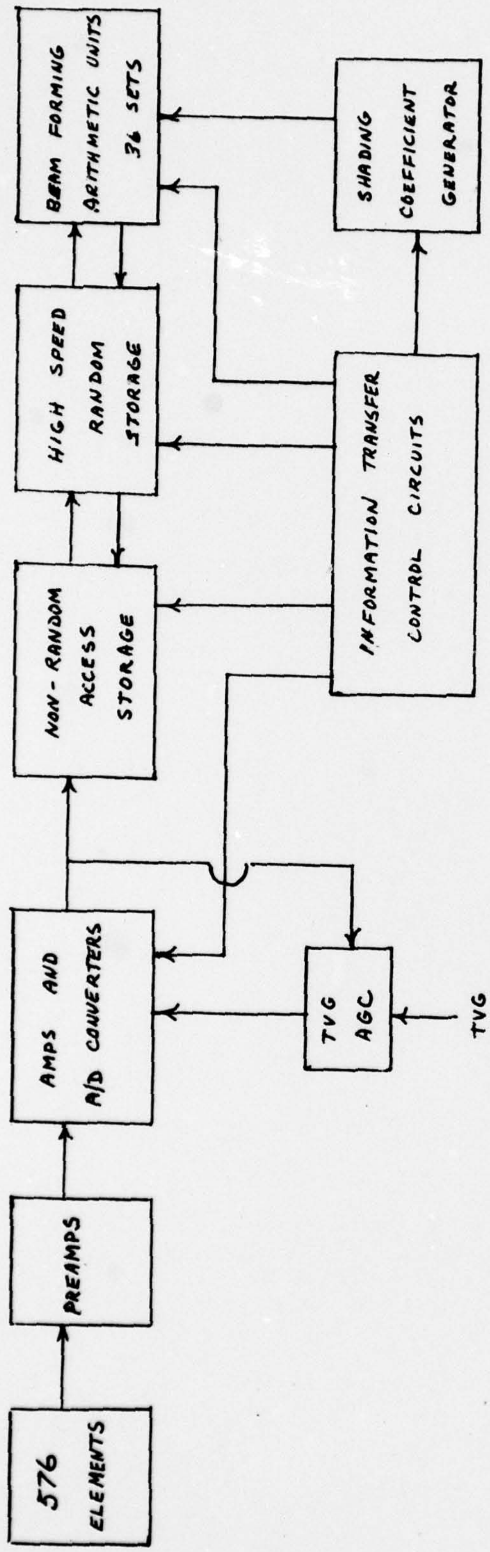
(3) Digital shading and phasing in both elevation and azimuth will be implemented in order to reduce sidelobes to acceptable levels.

Figure 1 shows a block diagram of the over-all system as presently envisioned. The outputs of the 576 transducer elements are each amplified in a set of preamps. These outputs are fed to a second set of amplifiers which are followed by analog-to-digital converters. The amplifiers indicated must include provision for insertion of AGC and TVG in order to maintain the A/D converters within their dynamic operating range. Feasible speeds for A/D converters indicate that time sharing of the converters is possible in the ratio of one converter to approximately 6 to 8 transducer elements. This assumes that quantization of the element outputs will be into two digits plus sign (i.e. 3 bits), at a sampling rate of 12 samples per cycle of the input signal frequency (i.e. approximately 3.5 kc/s). The total number of A/D converters required, therefore, should be between 72 and 100.

Preliminary beam pattern calculations indicate that sampling at 12 samples per cycle of the water frequency should be approximately sufficient to limit the beam distortion in the depressed beams. Somewhat lower sampling rates may be possible. A computer program is being implemented to allow rapid calculation of these patterns. The preliminary results imply that this will be the principal determining factor which limits reduction of sampling rate.

Following A/D conversion, the quantized element output samples are placed into digital storage to effect the time delays necessary for beam formation. To store sufficient information to permit the digital equivalent of phase shift beamforming requires storing samples from one-half cycle of the input signal from each element. An additional sample per element may be required to compensate for the non-instantaneous loading. Based on a sampling rate of 12 3-bit samples per cycle, the total storage requirement would be 12,096 bits.

TRACOR, INC. 1701 Guadalupe St. Austin, Texas 78701



BEAM FORMING SYSTEM BLOCK DIAGRAM

Figure 1

In Figure 1 the total storage is shown divided into two blocks. The first of these has the larger capacity and can consist of non-random access storage such as delay lines. The samples stored here are those not immediately required by the beamforming arithmetic unit. A second, smaller block of storage of the high-speed random access type (i.e. shift registers) is required for that portion of the data directly being processed by the arithmetic units. The necessity for this is created by the fact that clock rates in the arithmetic units and that portion of memory from which the arithmetic units receive samples must be much higher than can be attained in delay line storage. An effective time-compression is therefore required. This can be achieved by sub-dividing the memory as shown.

The final principal block of Figure 1 is a set of 36 high-speed arithmetic units in which the samples in storage are processed to form the 72 beams. Technically practical clocking rates in production micrologic are of the order of 30 megacycles. Working at this speed, each set of arithmetic equipment can be time shared between two beams to perform all the necessary shading coefficient multiplications and summations. Essentially each arithmetic unit set will consist of 3 3-bit registers, a high-speed multiplier consisting of logic circuits, a 3-bit product register and an accumulator for summing the products. A tentative basic cycle for this equipment has been designed. This assures that the equipment will be operating at near maximum capability.

In addition to the principal blocks described above and shown in Figure 1, some auxiliarly equipment is also required. One of these is a sequential digital number generator to generate the digital shading coefficients. This is shown separately from the arithmetic units since a single generator will suffice for all the arithmetic units.

The final block shown on Figure 1 includes the control logic for controlling the information transfers between the parts of the memory and the arithmetic units. It will consist principally of logic circuits with a small amount of storage. It will not be described here, however, since its structure will be complicated and the details depend heavily on the exact details of how the other parts of the system are mechanised.

Calculation of Directivity Patterns from a Digital Beamformer

A computer program has been written for the computation of direcitvity patterns from a digital beamformer. Both vertical and horizontal patterns can be computed for the SQS-26 transducer-digital beamformer combination. The purpose of this program is to determine the effect of the various parameters of a digital beamformer on the final direcitivty pattern. The parameters which can be investigated through this program are (1) the number of quantizing levels, (2) the sampling rate, (3) the phasing function for the formation of the horizontal beam or for tilting the vertical beam, (4) the amplitude shading function.

The program simulates an A/D converter which samples the input signal at time intervals τ and quantizes the samples into $(2)^k$ levels. This corresponds to a k-bit quantizer. The time delay phasing required to form the horizontal beam or to tilt the vertical beam is accomplished by allowing the quantized signals to shift phase only in discrete increments of the sampling time τ. This simulates the time delays which can be effected by digital storage. Finally the signals are scaled to account for amplitude shading and then summed to form the beam. In general, more than k bits are required to represent the scaled signals; consequently, the program simulates the process through which the scaled signals are rounded off to k-bits before the final summing.

One of the major problem areas in digital beamforming lies in the signal normalizer prior to the A/D converter. For ideal operation of the beamformer, the normalizer must keep the input signal constant to within better than one quantizing interval. The program incorporates a means for varying the input signal level with respect to the quantization levels. Thus the effect of poor normalization on the directivity pattern can be investigated.

Both vertical and horizontal directivity pattern calculations for 1-bit (hard clipped) and 3-bit quantization have been completed. These calculations were made for sampling rates in the range of 24 samples/period to 4 samples/period. On the basis of these computations it has been concluded that 3-bit quantization at a sampling rate of 12 samples/period is adequate to form the beams without undue distortion. The computations indicate that a sampling rate of less than 12 samples/period or that 2-bit quantization may be possible. Further calculations are required before a firm conclusion can be made.

Display Studies

The study comparing observers false alarm rates with computer clutter rates has been completed. The results of this study are being published in a technical note.

A preliminary analysis of observers' responses to the marking density test film strips shows little variation in probability of detection or probability of false alarm with changes in marking density. This would indicate that binary marking (mark or no mark) is not well-suited to a display of only six to twelve echo cycle histories. It will be recalled that in previous marking density studies using binary marking (SCENICS), data corresponding to some 50-100 echo-cycles was presented. Film strips employing multi-level marking will be generated for the marking density study.